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CENTRAL FLOW CONTROL AUTOMATION PROGRAM COST-BENEFIT ANALYSIS.(U)

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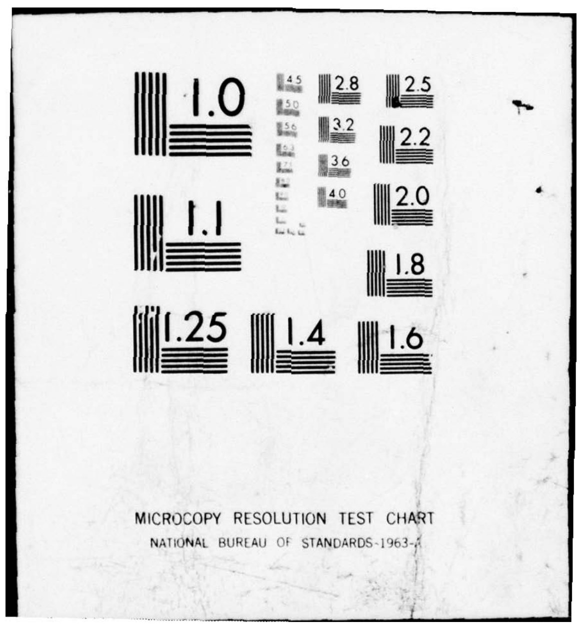
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CENTRAL FLOW CONTROL AUTOMATION PROGRAM
COST-BENEFIT ANALYSIS

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Thomas L. Hannan

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Final Report

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16. Abstract

This report contains an analysis of the benefits and costs associated with the Central Flow Control Automation Program. It presents the projected benefits and costs of both the current system and proposed system in terms of present-value dollars. Resultant benefit and cost differentials are discussed in terms of net present value and benefit-to-cost ratio. The sensitivity of these measures to major program uncertainty is described.

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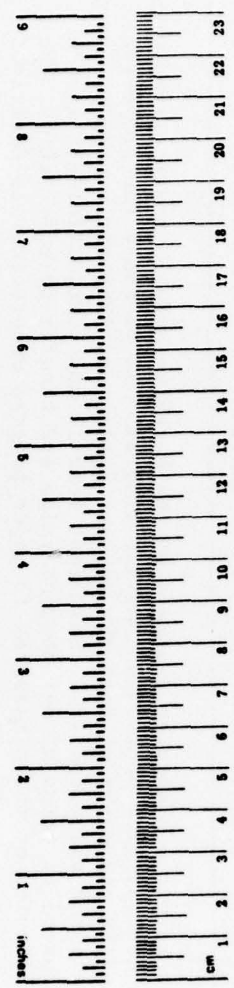
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

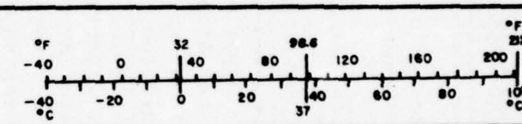
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



EXECUTIVE SUMMARY

This study contains an analysis of the benefits and costs associated with the Central Flow Control Automation Program. It presents the projected benefits and costs of both the current system and the proposed system in terms of present value dollars for comparison. The resultant benefit and cost differentials are then discussed in terms of net present value and benefit-to-cost ratio; and the sensitivity of these measures to major program uncertainty is described.

The analysis indicates that implementation of the proposed system will require a present value cost of $8,457,000 over the period FY-77-FY 1990, and will provide a present value benefit of $21,792,000 over the same period; thus yielding a net present value of $13,335,000 and a benefit-to-cost ratio of approximately 2.6. Adverse circumstances resulting in the doubling of both software costs and implementation period, the two areas in which estimates are least certain, would provide a program net present value of $5,734,000 and a benefit-to-cost ratio of approximately 1.5.

The primary benefit deriving from automation of the Central Flow Control function under both the current and proposed systems is the reduction of system-wide fuel consumption. This is in consonance with the Energy Policy and Conservation Act of 1975 which was enacted specifically to conserve energy supplies through energy conservation programs, and where necessary, through regulation of certain energy uses. Implementation of the proposed system will allow a net life cycle fuel savings of 142,781,000 gallons to be realized through extension of ground hold versus airborne hold procedures. In addition, safety should be enhanced and air pollution and airport noise reduced. The benefits to be derived from the proposed system are in addition to, and totally independent of, those to be derived from UG3RD elements currently under development, but are in concert with the operational objectives of these and other components of the National Airspace System.

The overall conclusion of this study is that the benefits of implementing the advanced Central Flow Control Automation Program are significantly greater than the costs, and that development and implementation should be continued.

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1.0 INTRODUCTION

1.1 Background

The Air Traffic Control System Command Center (ATCSCC) was established in 1970 to oversee the flow of aircraft among the Air Route Traffic Control Centers. Its primary objective is the balancing of national air traffic flow to minimize delays without exceeding controller capacity.

Prior to the establishment of the ATCSCC, flow control concepts were primarily reactive and defensive. In general, individual facilities tended to adjust the flow of traffic in response to problem situations without giving adequate regard to their effect on the rest of the ATC systems.

In an attempt to reduce the proliferation of flow restrictions, the Air Traffic Service established an experimental centralized flow control facility in December 1968. Limited automation support for the facility was provided in January 1970 by using a MITRE programmed IBM-9020A simplex system located in the Kansas City ARTCC. The automation support was primarily in the area of predicting demand at large terminals to support Advanced Flow Control Procedures (AFCP) developed by the Air Traffic Service. Due to the success of the experimental facility, in mid-1970 it was made a permanent facility of Air Traffic Service.

In 1971, the FAA projected ever increasing workload requirements for the ATCSCC and a decision was made to begin an evolutionary development of more advanced Flow Control Procedures. Since the demands for computer resources at the Kansas City ARTCC would exceed the available capacity if the flow control automation program remained there, and since further refinement and experimentation was required to develop the procedures required by Central Flow Control, the Transportation Systems Center was tasked with developing an experimental prototype flow control system. In January 1972, a program named the "Airport Information Retrieval System" (AIRS) was placed in operation by the Transportation Systems Center using a commercial time-shared computing system. This prototype system has been used by the Air Traffic Service as a quasi-operational automated Central Flow Control facility from 1972 to date. Refinements and modifications to the original AIRS have been tested in an attempt to define the basic functional capabilities required of a fully operational automated Central Flow Control Facility to be incorporated into the National Airspace System.

In December 1975, the Air Traffic Service documented the basic requirements based upon almost four years of experience with AIRS. These basic requirements underwent detailed analysis by an inter-service task force comprised of Air Traffic Service, Airway Facility Service, Systems Research and Development Service, Transportation Systems Center, and contractor personnel; and a detailed specification for an Advanced Central Flow Control Facility acceptable to all participating Services was produced.

This study presents the results of analysis of the costs required to upgrade the Central Flow Control function for fully operational incorporation into the National Airspace System, an analysis of the benefits to be accrued from the incorporation of the operational system, and the cost/benefit relationship anticipated.

1.2 Purpose

The purpose of this study and the analyses conducted during its development are summarized as follows:

1. To define the cost elements associated with the present and advanced Central Flow Control Automation programs and determine the differential dollar costs associated with an upgrade to the advanced system.

2. To define the sources of benefit associated with the present and advanced Central Flow Control Automation programs and determine the differential dollar benefits associated with an upgrade to the advanced system.

3. To determine and evaluate the relationship of the change in cost and the change in benefit resulting from the change in Central Flow Control Automation.

1.3 Scope and Organization

The remainder of this study presents the methodology and results of the cost/benefit analysis. Section 2 contains a description of the methods of cost and benefit calculation and establishes the dollar value of present and advanced system costs and benefits. Section 3 contains a description of the method of cost/benefit analysis, taking into consideration the time value of money. Appendix A contains a detailed description of the modeling methodology used to determine the dollar value of benefits associated with the present and the advanced Central Flow Control Automation programs. Appendices B, C, and D detail the underlying modeling assumptions and the sensitivity of the modeling results to these assumptions. Appendix E lists the references from which information was obtained during the course of the study, and Appendix F lists the sample set of problem days from which benefits may accrue. Appendix G provides an analysis of the impact of cost escalation and implementation delay on the benefit-to-cost ratio arrived at in the study.

2.0 COST AND BENEFIT CALCULATION

2.1 General

The dollar value quantifications contained in this section are presented so that the differential dollar costs and benefits associated with a change from the present to the advanced system can be

determined. The costs and benefits associated with the present system define the state with no change, the costs and benefits associated with the advanced system define the state with change. Section 3 presents the differential dollar flow and evaluates the advisability of change.

The cost quantifications contained in this section include plant, equipment, and personnel costs. Costs are broken down by Facilities and Equipment (F&E), Operations and Maintenance (O&M), and Other categories, and are shown for FY-77, FY-78, FY-79, and FY-80-90. The present system costs are based upon experienced costs data, the advanced system costs are based upon projections derived from the efforts of an interservice task force which has prepared detailed functional specifications for the the advanced system. All costs are in terms of current dollars with no escalation index applied.

The present ATCSCC system was reviewed and the following types of benefits were identified due to Central Flow Control Automation:

(a) greater ATC system operating efficiency

(b) increased safety

(c) reduced aircraft operations costs, including fuel consumption, due to the transfer of delays from the airborne holds to ground holds by usage of Fuel Advisory Departure (FAD) procedures

(d) increased accuracy in advisories to aircraft operators of anticipated arrival delays and their forecasted length, thereby giving the user the option to reschedule flights and reduce diversions and cancellations

(e) improved reaction to a major unscheduled outage such as the loss of communications at a center

In performing a detailed analysis of the available data, significant quantifiable differential benefits were found only in area (c), above. The primary quantifiable differential benefit in this area was determined to be the reduction in fuel consumption attributable to the transfer of airborne delay to ground delay through the implementation of FAD procedures.

Automated simulation techniques were used to examine delays experienced by traffic arriving at major airports during 1975. Potential fuel savings accruing from application of FAD procedures was based upon manufacturer and airline supplied fuel consumption data. Given estimates of future demand at the same major airports through 1990, and a constant number of delay days per year, long-term fuel

savings were extrapolated from the 1975 results. Appendix A contains a detailed description of the simulation technique used, the input data and its source, and the assumptions made.

2.2 Present System

2.2.1 Overview

The present Central Flow Control Automation program consists of an experimental system implemented on a commercial time-sharing computer complex accessible to the Systems Command Center by dial-up and transmission over the voice-grade channels of the commercial telephone switched network. Demand predictions and FAD procedure assignments are calculated based upon a bi-weekly schedule of air-carrier/air-taxi flights, manually entered flight schedule updates and Airport Reservation Office (ARO) information, and manually entered operational data including airport landing capacity, departure delay, and general aviation estimates. This system has been in use as a quasi-operational facility since 1972, and has proven to be a significant improvement over predecessor systems of more limited scope. Documentation of the overall design concept and operating instructions has been completed and is currently in use.

2.2.2 Cost Calculation

Table 1 details the expected costs of the present system from the present to 1990. F&E cost represents software documentation remaining to be accomplished prior to FAA acceptance of the system for maintenace. O&M costs represent staffing costs to Air Traffic Service for system operation and maintenance. Other costs reflect communications line charges, air-carrier/air-taxi schedules (machine-readible), and computer leasing charges.

2.2.3 Benefit Calculation

The present system accrues benefit from fuel savings due to FAD procedure implementation when arrival delays significantly exceed a 48-minute threshold. Simulation results for the major airports studied for the year 1975 indicate a total of 58 delay days for which this threshold would have been significantly exceeded. Appendix A describes the simulation techniques applied. Appendix F lists the delay days and the causes of capacity reduction. Table 2 details the expected benefit attributable to fuel savings resulting from FAD procedure implementation in 1975. Using FAA demand data, the simulation was repeated for 1980, 1985, and 1990 with the results shown in Table 2.

TABLE 1

Present System Costs ($ X 1000)

	FY-77	FY-78	FY-79	FY-80-90
F&E				
Documentation	225			
O&M				
Personnel (I-house)				
1 Chief 2 Secretaries 11 Flow Controllers	616	616	616	616/year
10 Data Systems Specialists	249	249	249	249/year
Personnel (Contract)				
5 Weather Specialists	143	143	143	143/year
OTHER				
Voice Communications (leased)	337	337	337	337/year
Schedule Tapes	54	54	54	54/year
Computer Leasing	560	560	560	560/year
TOTAL	2184	1959	1959	1959/year

TABLE 2

Present System Benefits

Year	Gallons (000)	Dollars (000)
1975	8,551	2,651
1980	18,494	5,733
1985	25,235	7,823
1990	29,948	9,284

2.3 Advanced System

2.3.1 Overview

The advanced Central Flow Control Automation program will consist of an operational system implemented on a dedicated IBM 9020A computer complex accessible to the Systems Command Center by dedicated lines conditioned for data transmission. Demand predictions and FAD assignments will be calculated based upon a reference data base of flight schedule data augmented by real-time flight progress reports transmitted via the NAS En Route communications network. Additional flight schedules and operational data such as airport landing capacity, departure delay, and general aviation estimates will be manually entered from the Systems Command Center. Operating requirements, including detailed message formats, were documented by Air Traffic Service in December 1975. Computer Program Functional Specifications (CPFS) for the system were documented in May 1976 with the concurrence of Air Traffic Service, Airways Facilities Service, and Systems Research and Development Service. Specifications include development of complete operating and maintenance documentation required for FAA acceptance of system responsibility.

2.3.2 Cost Calculation

Table 3 details the expected costs of the advanced system from installation to 1990. F&E cost represents hardware and facility installation costs and estimated software costs based upon industry proposals submitted in response to an FAA RFP containing the CPFS developed by the interservice task force. O&M costs represent staffing costs to Air Traffic Service for system operation and maintenance and staffing costs to Airways Facilities Service for hardware maintenance. Other costs reflect transitional computer leasing and air-carrier/air-taxi schedules, communications line charges, and provisioning and spare costs for the advanced system.

2.3.3 Benefit Calculation

The advanced system accrues benefit from fuel savings due to FAD procedures implementation when arrival delays significantly exceed a 30-minute threshold. Simulation results for the major airports

TABLE 3

ADVANCED SYSTEM LISTS ($ X 1000)

	FY-77	FY-78	FY-79	FY-80-90
F&E				
Hardware & Facilities	2730			
Software	1000	2000	2000	
O&M				
Personnel (In-house)				
1 Chief				
2 Secretaries	616	616	616	616/year
11 Flow Controllers				
10 Data Sys. Specs.	249	249	249	249/year
4 Data Sys Specs. (add'l)			81	81/year
5 Maintenance Engineers		132	132	132/year
Personnel (Contract)				
5 Weather Specialists	143	143	143	143/year
OTHER				
Voice Communications (leased)	337	337	337	337/year
Schedule Tapes	54	54	54	54/year
Computer Leasing	560	560		
Data Communications (leased)		200	200	200/year
Provisioning & Spares	258	258	258	258/year
TOTAL	5947	4549	4070	2070/year

studied for the year 1975 indicate a total of 68 delay days for which this threshold would have been significantly exceeded. Appendix F lists the delay days and causes of capacity rediction.

Table 4 details the expected benefit attributable to fuel savings resulting from FAD procedure implementation in 1975. Using FAA demand data, the simulation was repeated for 1980, 1985, and 1990 with the results shown in Table 4.

TABLE 4

Advanced System Benefits

Year	Gallons (000)	Dollars (000)
1975	13,975	4,332
1980	28,526	8,788
1985	37,581	11,651
1990	43,896	13,607

3.0 COST/BENEFIT ANALYSIS

3.1 General

The dollar value quantifications of costs and benefits presented in the previous section enable a calculation of the future net change in benefit resulting from the future net change in cost attributable to the upgrade of the Central Flow Control Automation program. This section presents the differential costs and benefits accruing from the upgrade, and presents the present value of these differentials.

3.2 Differential Cost

Table 5 presents the annual projected costs for the present and advanced systems for the fiscal years 1977 through 1990 inclusive, and presents the differential costs for a change from the present system to the advanced system for the same period. Costs data is taken directly from Tables 1 and 3.

TABLE 5
Differential Costs ($ X 1000)

Fiscal Year	Present System Costs	Advanced System Costs	Differential Cost
77	2184	5947	3763
78	1959	4549	2590
79	1959	4070	2111
80	1959	2070	111
81	1959	2070	111
82	1959	2070	111
83	1959	2070	111
84	1959	2070	111
85	1959	2070	111
86	1959	2070	111
87	1959	2070	111
88	1959	2070	111
89	1959	2070	111
90	1959	2070	111
TOTAL	27651	37336	9685

3.3 Differential Benefit

Table 6 presents the annual projected benefits for the present and advanced systems for the fiscal years 1977 through 1990 inclusive, and presents the differential benefits to a change from the status quo for the same period. Benefit data is based upon Tables 2 and 4. Linear interpolation is used to estimate benefits for those years for which simulation results were not computed.

TABLE 6
Differential Benefits

Fiscal Year	Present System Benefits ($ X 1000)	Advanced System Benefits ($ X 1000)	Differential Benefits ($ X 1000)
77	3884	3884	0
78	4500	4500	0
79	5117	7897	2780
80	5733	8788	3055
81	6151	9361	3210
82	6569	9933	3364
83	6987	10506	3519
84	7405	11078	3673
85	7823	11651	3828
86	8115	12042	3927
87	8407	12433	4026
88	8700	12825	4125
89	8992	13216	4224
90	9284	13607	4323
TOTAL	97667	141721	44054

3.4 Present Value of Investment

Table 7 presents the differential costs and benefits associated with the change from the present to the advanced Central Flow Control Automation program adjusted by standard present value techniques with a discount rate of 10 percent. Differential cost and benefit data are taken from Tables 5 and 6, and an annual net present value computation is shown.

TABLE 7
Present Value of Investment
($ X 1000)

Fiscal Year	Discounted Differential Costs	Discounted Differential Benefits	Net Present Value
77	3763	0	(3763)
78	2354	0	(2354)
79	1744	2296	552
80	83	2294	2211
81	76	2192	2116
82	69	2089	2020
83	63	1985	1922
84	57	1884	1827
85	52	1788	1736
86	47	1665	1618

Fiscal Year	Discounted Differential Costs	Discounted Differential Benefits	Net Present Value
87	43	1554	1511
88	39	1444	1405
89	35	1347	1312
90	32	1254	1222
TOTAL	8457	21792	13335

3.5 Conclusions

This study indicates that the change from the present system to the advanced system results in a differential present value dollar cost of $8,457,000 and a differential present value dollar benefit of $21,792,000 over the period 1977-1990. This represents a positive net present value dollar return of $13,335,000 which would be foregone if the advanced system were not implemented; and a positive benefit-to-cost ratio (BCR) of approximately 2.6. If further indicates a net reduction in system-wide fuel consumption of approximately 142,781,000 gallons over the projected advanced system life.

A further study (Appendix G) was conducted to determine the sensitivity of the advanced system's benefit-to-cost relationships to major program uncertainties. Benefit estimations for both the present and advanced systems were obtained from the same model; modeling uncertainties affect both estimates, and impact on differential benefits would not be major. Hardware and personnel costs for both the present and advanced systems have a relatively minor degree of uncertainty associated with them. Software development costs and implementation period were identified as the only major program uncertainties, and were examined in detail. Results indicate that a cost slightly less than four times the estimate would yield a positive BCR greater than 1.0; a period slightly less than five times the estimate would yield a positive BCR greater than 1.0; and a combination of cost and period each greater than 2½ times the estimates would also yield a positive BCR greater than 1.0.

Based on the above, the conclusion of this study is that the benefits quantified support the continuation of the Central Flow Control Automation Program, and that the positive net return and benefit-to-cost ratio of the program which would persist even under the most adverse of circumstances substantiate the value of additional investment.

In addition to the quantifiable benefits identified, the advanced system offers a further significant advantage - agency control over the computing resources needed to effect centralized traffic management. The

present system is comprised of hardware and software components alien to the ATC system. Maintenance and operation of the present system are not under the control of agency personnel, and the present system's configuration does not conform to agency operational systems standards. The advanced system, however, will be totally under the control of agency personnel, and will be in complete compliance with all operational standards.

The overall conclusion of this study is that the benefits of implementing the advanced Central Flow Control Automation program are significantly greater than the costs. It is therefore concluded that its development and implementation should be continued.

APPENDIX A*

Method of Benefit Estimation

In order to quantify the change in fuel savings benefit attributable to the change in automation capability, it was necessary to develop two fuel savings forecasts over the expected life of the advanced system. The first forecast provided an estimate of fuel savings under the operational capabilities of the present system, and the second forecast provided an estimate of fuel savings under the operational capabilities of the advanced system.

INITIAL STUDY

The initial study undertaken in this analysis provided an estimate of the fuel savings that would have accrued from Fuel Advisory Departure (FAD) procedure use under the operational capabilities of the present system during the year 1975.** A detailed description of this study and its findings is contained in Appendix B. The basis for the conversion of the reduction in airborne time to a reduction in fuel usage, and hence operating cost, is contained in Appendix C. The sensitivity of the estimation model used in this study to assumptions regarding fuel consumption rates and traffic load redistribution is described in Appendix D.

BASELINE USE

The initial, baseline, study effort identified the available sources of data that could be drawn upon, and indicated a basic methodology that could be used to forecast fuel savings. The simulation model used in the baseline study incorporated the actual automation program of the present system, and thus provided the most accurate estimate of the present system's fuel savings capability available. Since, however, the simulation model was a modification of an existing automation program oriented towards the solution of individual problem occurrences, it did not lend itself to cost effective use for estimation involving a large number of problem occurrences.

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* The Benefit Analysis of Central Flow Control Automation discussed in this appendix will be covered in greater detail in a report to be published by the Transportation Systems Center.

**Predicated upon Performance Summary Profile (PSP) data obtained from a preliminary scan of Air Traffic Service data files which were subjected to more detailed analysis later in the study.

SIMULATION MODEL

In order to circumvent this problem, a specialized event-driven simulation model capable of processing multiple problem occurrences in a single execution was developed. This model, called the Benefit Analysis Simulation (BAS), incorporated the salient features of the baseline model, and in order to confirm its validity as an estimation tool, was calibrated against it. Results of calibration indicated deviations of only 1.8 percent for estimation of present system fuel savings potential during 1975, 2.2 percent for estimation of advanced system fuel savings potential during 1975, and 3.1 percent or less for estimation of both present and advanced system fuel savings potential for 1990.

SIMULATION OBJECTIVES AND REQUIREMENTS

The objective of modelling using BAS was to produce a sufficient number of fuel savings estimates under both present system and advanced system capabilities over the expected life of the advanced system so as to enable calculation of differential fuel savings on an annual basis. To accomplish this, two sets of data were required, the number of expected demand/capacity imbalance occurrences of sufficient magnitude to warrant FAD procedure invokation, and the hourly demand and capacity figures for each expected occurrence.

AIRPORT SELECTION

Four airports representing the major source of imbalances warranting FAD procedures, and thus representing the major source of benefit estimation data, were selected. The four were the same airports used in the baseline study; Chicago (ORD), Kennedy (JFK), La Guardia (LGA), and Atlanta (ATL).

CASE SELECTION

Historical data for these four airports during the year 1975 was analyzed and imbalance occurrences warranting FAD procedures were identified. A total of 68 such occurrences were identified, and the necessary hourly demand and capacity figures for each were obtained. Appendix F lists the occurrences by airport and date, and indicates the causes of imbalance.

SIMULATION USE

In order to develop fuel savings estimates on an annual basis, four equally spaced years spanning the period from baseline to the end of the expected advanced system's life cycle were subjected to complete simulation; estimates for the intervening years to be developed through linear interpolation. The years subjected to complete simulation were 1975, 1980, 1985, and 1990.

PROBLEM OCCURRENCE AND DEMAND ASSUMPTIONS

Analysis of historical imbalance occurrence data for 1975 indicated that, in general, occurrences resulted from unforeseen and unpredictable incidents such as thunderstorms, runway outage due to snow, accidents, etc. Due to the unpredictability of such instances, the number of occurrences was held constant for each year simulated. The demand composition for each occurrence in each of the four years was also held constant based upon the actual composition identified during the baseline study; the demand magnitude, however, was adjusted on a yearly basis in accordance with traffic growth forecasts (Ref. 21). Growth factors used for the four airports for the four years simulated were as follows:

Year/Airport	ATL	JFK	LGA	ORD
1975	1.000	1.000	1.000	1.000
1980	1.175	1.206	1.062	1.079
1985	1.275	1.347	1.121	1.091
1990	1.205	1.458	1.150	1.101

HOLDING STACK CONSTRAINTS

The operational capabilities of the present system are constrained to FAD procedure implementation resulting in the maintenance of a predicted destination holding stack size of approximately 48-minutes' worth of projected airport landing capacity in order that sudden increases in landing capacity can be taken advantage of rather than going unused. The 48-minute parameter is a target value taking into allowance variances in prediction accuracy inherent in the present system's static demand database.

The operational capabilities of the advanced system are conservatively estimated as being constrained to FAD procedure implementation resulting in the maintenance of a predicted holding stack size of approximately 30-minutes' worth of projected airport landing capacity. Relaxation of the holding stack size parameter is enabled by the increase in predictive accuracy inherent in the advanced system's dynamic demand database.*

GROUND DELAY ASSIGNMENT LIMITATIONS

The present system's operational capabilities limit assignment of flow controlled ground delays to those aircraft whose flight time to the impacted destination does not exceed 2½ hours. Due to its more accurate predictive ability and more extensive flow control advisory dissemination capabilities, the advanced system is limited in its ground delay assignment to those aircraft destined for the impacted terminal whose airport of origin lies within the bounds of the CONUS.

BENEFIT ESTIMATION

Of the imbalance occurrences identified during analysis of 1975 data for the four airports selected, 58 occurrences warranted FAD procedure implementation under the operational capabilities of the present system and all 68 occurrences warranted FAD procedure implementation under the operational capabilities of the advanced system. The BAS model was executed for each of the 58 occurrences applicable to the present system for each of the four years of interest, with the appropriate traffic growth factor being applied in each year. The following results were obtained:

YEAR	SAVINGS (GAL. X 1000)	SAVINGS ($ X 1000)
1975	8551	2651
1980	18494	5733
1985	25235	7823
1990	29948	9284

The model was executed for each of the 68 occurrences applicable to the advanced system for each of the three years of interest during which

* A treatment of dynamic CFC database accuracy parameters is contained in Reference 22, Section 4.1.1.

it would be operational, with the appropriate traffic growth factor being applied in each year. The following results were obtained:

YEARS	SAVINGS (GAL. X 1000)	SAVINGS ($ X 1000)
1975	13975	4332
1980	28526	8788
1985	37581	11651
1990	43896	13607

APPENDIX B

BASELINE SIMULATION METHODOLOGY

The presently operational Airport Information Retrieval System (AIRS) was modified to include an option for the calculation of fuel saving benefits due to the imposition of FAD Procedures. Briefly, the initial program retrieves the actual hourly scheduled aircraft and estimates of general aviation traffic, including Airport Reservation Office (ARO) updates, from its data base. Estimated hourly airport arrival capacity and an allowable terminal area delay time are entered. The program then calculates the estimated terminal delays for all aircraft. Based on the estimated time of departures from the originating airports, ground delays for each individual aircraft are calculated so each aircraft will be delayed in the terminal area by the entered hourly terminal delay. The additional option calculates the fuel saving benefits for eight categories of aircraft. The outputs includes by aircraft category, the number of aircraft delayed, the total delay time, the ground delay during the FAD Period, the fuel savings in gallons, the dollar savings, the number of aircraft ground delayed during the FAD Period, and the number of aircraft delayed (air and ground) during the FAD Period. Aggregations of these figures are also included.

Selection of Cases to be Simulated

Discussions with ATCSCC personnel indicated that for Flow Control to be applied, the number of daily arrival delays greater than 30 minutes should exceed 100 aircraft. The ATCSCC Daily Resumes and RECAP sheets were then scanned and the Performance Summary Profile (PSP) sheets collected for all days with 30 minute delays exceeding approximately 90 aircraft. Since the PSP's were only kept for DCA, EWR, JFK, LGA, and ORD, there were possible delay cases at other airports (BOS and LAX) which could not be simulated. In addition, one PSP was missing from ORD so this day was not simulated. The PSP's were then reviewed and a number of days were eliminated for the following reasons:

1. The PSP's indicated that aircraft delay times were less than the FDAP 48 minute criteria (The 48 minute criteria is based on the fact that the nominal ORD approach phase is 12 minutes. The addition of these two figures is an hour in the terminal area).

2. The time period when delays exceeded 48 minutes was not sustained for a sufficient period for the application of FAD Procedures.

Simulation Runs

The simulation runs were made by utilizing the data on the PSP's. Capacity was equated to the PSP actual hourly arrival data. In the cases where this data was not recorded either of two assumptions were made: (1) capacity was assumed to equal the nominal VFR capacity of the airports; (2) if the PSP data indicated delays had occurred in the missing actual arrival periods, capacity figures were estimated by graphical extrapolation using the hourly demand and the time and magnitude of the delays. The airport capacity values used are contained in table B-1.

The hourly demand was extracted from the PSP's by the addition of the hourly OAG scheduled Air Carrier/Air Taxi and the actual General Aviation/Military arrivals. It can be assumed that some of the scheduled AC/AT traffic was alternatively cancelled, diverted, or delayed to a later hour. Therefore, the simulation results have some degree of inaccuracy in this respect. A total of 31 runs were made.

Adjustment for Demand Data Differences

The AIRS primary and test systems' data bases contain demand data for the current, previous, and subsequent months. The only way to simulate the 1975 cases was to utilize this data base. However the hourly demand for the 1975 cases differed from the available 1976 data. This problem was circumvented as follows:

1. For each problem day in 1975 the hourly demand and capacity were tabulated.

2. The hourly demand for the 1976 day used for simulation purposes was retrieved from the computer system.

3. The hourly differences between the 1976 day and each 1975 problem day were determined to obtain demand numbers.

4. The 1975 hourly capacity numbers were then adjusted by the demand numbers.

5. These adjusted capacity numbers were then entered into the AIRS program and the simulation runs made.

The benefits of the problem days that occurred in October 1975 were simulated in November 1975 using the actual days' AIRS demand data. A verification run was made for the October 24, 1975, using the above methodology and compared to the originial run. The results are delineated below for the FDA Period.

	Original Run	New Run	Percent Difference
Predicted Delays- Minutes	52,507	52,410	0.2%
Predicted Delays- No. of A/C	362	354	2.2%
% of Delay Time Shifted to Ground	55	54	1.8%
% of A/C Ground Delayed	85	80	6.2%
Gallons of Fuel Saved	402,449	406,120	0.9%

These results are considered to have an excellent correlation and the same methodology was used for all runs made for the baseline simulation study.

Estimation of Missing Capacity Data

The Performance Summary Profiles generally had any reduced hourly capacity figures delineated. In several cases, these figures were missing but the time the delays reach 30 minutes were recorded. Using this recorded time, the capacities were estimated as follows:

(1) A graph was plotted of the hourly demand rate.
(2) The time where the delays initially exceeded minutes was plotted on the graph.
(3) A line parallel to the time axis scaled for 30 minutes was plotted between the demand curve and the initial 30 minutes delay.
(4) A line drawn between the origin and the 30 minute delay line intersection yields the hourly capacity rate.

RESULTS AND CONCLUSIONS

For the 31 simulation runs made the following savings due to the imposition of FAD procedures were calculated:

- 5,969,465 gallons of fuel saved
- $1,804,949 saved resulting from the above fuel savings since only data from January 1975 through November 1975 was included, the above results were extrapolated for a full year by a multiplication factor of 12/11. Therefore, the benefits for the full year are considered to be:
  - 6,512,144 gallons of fuel saved
  - $1,969,035 saved resulting from the above fuel savings

These results are conservative since no December data was simulated which is one of the severe weather months.

These results are delineated in Table B-2. A review of the table shows that four airports (ORD, JFK, LGA, and ATL) contributed the entire yearly benefits. As would be expected, the majority of the benefits were accrued at ORD.

Several days were not simulated due to lack of data. However, the above results can be considered conservative as discussed in the following paragraphs.

Of the total benefits for the 11 months 66 percent occurred in January, February, and November. Therefore, the yearly figure calculated by weighting December equally with all months is conservative. A weighting factor in the order of 1.2 could have been rationalized resulting in a 10 percent increase in the total yearly benefits, (During December 1975, United Airlines was on strike so it would not be considered a typical December FAD procedure benefits).

The minimum holding fuel consumption rates were selected for the various aircraft. The manufacturers' data for holding fuel consumption rates generally calculated for optimum fuel consumption at a particular altitude. Dependent on the holding patterns used it is probable that the average fuel consumption rate would be somewhat higher. Extension of flaps results in a fuel consumption rate increase in the order of 10 to 20 present.

TABLE B-1

CAPACITY DATA USED IN FADP SIMULATIONS

ORD

GMT \ DATE	1-8	1-9	1-29	2-5	2-15	2-23	2-25	3-27	4-2	4-3	6-17
1200									32		
1300				22	42		44		32		
1400	33		23	19	47		47		27		
1500	29		46	23	48		47	34	29		37
1600	28	52	42	14	43	47	50	52	35	Airport	54
1700	37	50	48	18	56	53	49	52	29	Closed	46
1800	57	59	52	52	48	63	52	55	7		46
1900	53	58	55	57	52	50	53	51	1		75
2000	62	57	55	42	51	47	56	52	0		71
2100	55	61	56	59	60	62	55	55	Airport	[illegible]5	66
2200	61	57	53	57	54	53	57	58	Closed	23	73
2300	68	60	64	52	53	55	52	59		30	70
0000	75	65	62	55	55	56	51	55		30	69
0100	61	54	67	62	37	43	53	49		26	63
0200		60	64	63	42	30	75	50		22	30
0300						40				20	
0300						30				23	
0500											

NOTE: ALL BLANKS AND OTHER HOURS ASSUMED 65

TABLE B-1 (cont'd)

CAPACITY DATA USED IN FADP SIMULATIONS

ORD (CONTINUED)

GMT / DATE	10-17	10-22	10-23	10-24	10-31	11-26
1200						
1300			62			
1400			58	58		60
1500			64	57		56
1600		53	49	64		46
1700		59	66	61		51
1800		63	63	57	55	62
1900		72	63	61	58	65
2000	60	67	67	50	53	57
2100	58	63	65	45	55	62
2200	60	65	65	44	62	54
2300	59	64	61	40	55	54
0000	55	62	60	21	61	45
0100	60	59	69	37	67	47
0200	60			36	62	32
0300						29
0400						37
0500						

NOTE: ALL BLANKS AND OTHER HOURS ASSUMED 65

TABLE B-1 (Cont'd)

CAPACITY DATA USED IN FADP SIMULATIONS

JFK

GMT / DATE	1-11	3-19	6-24	7-13	8-25	8-26	11-12
1400				10			
1500				12			
1600		7	9	14	5	18	
1700	16	23	24	18	17	15	9
1800	8	20	36	26	34	28	6
1900	6	23	35	27	27	31	0
2000	9	26	1	28	31	31	0
2100	16	23	24	34	37	32	28
2200	27	24	32	23	30	21	31
2300	29	29	17	30	33	28	18
0000	25	23	32	31	32	30	30
0100		26	30	34		27	21
0200			41				25
0300							9

NOTE: All Blanks and Other Hours Assumed 45

TABLE B -1 (Cont'd)

CAPACITY DATA USED IN FADP SIMULATIONS

	LGA				ATL		
GMT \ DATE	1-13	3-19	11-21	11-30	2-23	3-12	11-24
1200	10		10			10	
1300	25		26			15	0
1400	31		24			40	6
1500	28		25			54	43
1600	28	7	19		47	52	52
1700	17	23	19	14	53	25	49
1800	21	20	22	9	63	43	46
1900	23	23	24	25	50	46	41
2000	19	26	30	25	47	31	38
2100	14	23	23	33	62	52	34
2200	17	24	25	28	53	33	57
2300	28	29	27	27	55	59	24
0000	23	23	26	31	56	28	56
0100	32	26	32	30	43		
0200	30		27	31	30		
0300					40		
0400					30		
0500							

NOTE: ALL BLANKS AND OTHER HOURS ASSUMED 40 FOR LGA
50 FOR ATL

GRAPHICAL EXTRAPOLATION OF HOURLY CAPACITY

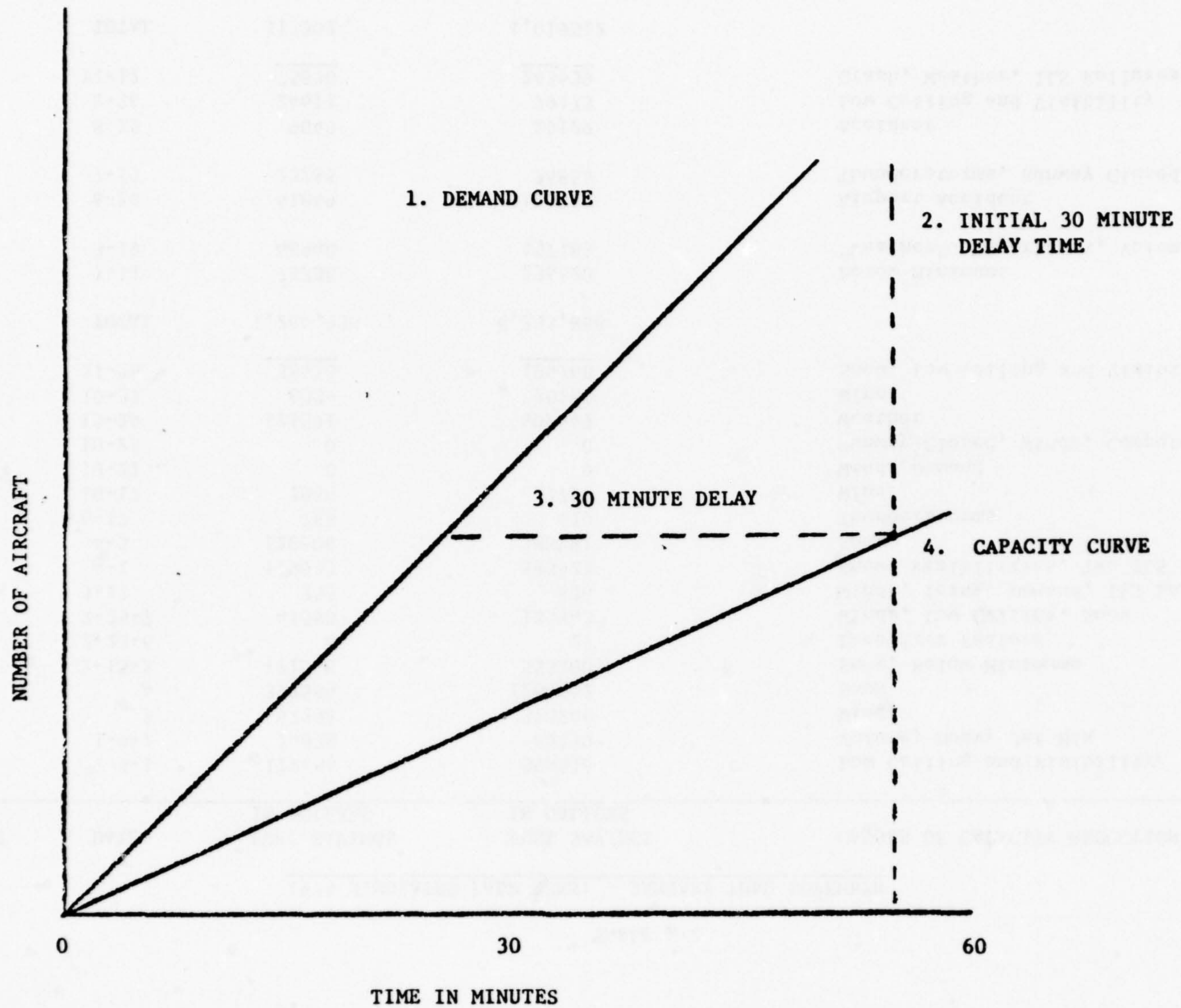

TABLE B-2

1975 SIMULATED FADP RUNS: JANUARY THRU NOVEMBER

AIRPORT	DATE	FUEL SAVINGS IN DOLLARS	FUEL SAVINGS IN GALLONS	CAUSES OF CAPACITY REDUCTION
ORD	1-8-1	122466	394518	Low Ceiling and Visibility
ORD	1-9-2	24878	80139	Volume, Heavy Jet Mix
ORD	3	97238	313206	Winds
ORD	4	392594	1264632	Snow
ORD	2-15-5	171548	553200	Snow, Below Minimums
ORD	2-23-6	8	27	Localizer Failure
ORD	2-25-7	41588	133943	Winds, Low Ceiling, Snow
ORD	3-27	255	826	Winds, Icing, Demand, ILS Loss
ORD	4-2	119033	383523	Snow, Visibilities, Two ILS Failures
ORD	4-3	120806	388991	Snow
ORD	6-17	188	610	Thunderstorms
ORD	10-17	3986	12759	Winds
ORD	10-22	0	0	Winds, Demand
ORD	10-23	0	0	Runway Closed, Winds, Computer Outage
ORD	10-24	125591	402449	Weather
ORD	10-31	6339	20285	Winds
ORD	11-26	38418	284760	Snow, Low Ceiling and Visibility
ORD	TOTAL	1,264,936	4,233,868	
JFK	1-11	73738	236820	Below Minimums
JFK	3-19	48940	157183	"Weather". Departures, Volume Configuration
JFK	6-24	61849	198714	Airport Accident
JFK	7-13	23285	74854	Thunderstorms, Runway Closed for Inspection
JFK	8-25	9049	29129	Accident
JFK	8-26	24611	79173	Low Ceiling and Visibility
JFK	11-12	75830	243639	Crash, Weather, ILS Failures
JFK	TOTAL	317302	1,019512	

TABLE B-2 (continued)

1975 SIMULATED FADP RUNS: JANUARY THRU NOVEMBER

AIRPORT	DATE	FUEL SAVINGS IN DOLLARS	FUEL SAVINGS IN GALLONS	CAUSES OF CAPACITY REDUCTION
LGA	1-13	18374	59183	Weather and Sanding of Runway
LGA	3-19	40657	130923	Winds
LGA	11-21	19627	63229	Winds, Wet Runways
LGA	11-30	8137	26226	Winds, Visibility
LGA	TOTAL	86795	279561	
ATL	2-23	56776	182123	Below Minimums
ATL	3-12	36035	115829	Low Ceiling, Visibility, and RVR
ATL	11-24	43105	138572	Below Minimums, Runway Repairs, Wind
ATL	TOTAL	135916	436524	
Total for four Airports - 11 mos.		$1,804,949	5,969,465 Gallons	
1975 Estimated Total (12/11 x above)		$1,969,035	6,512,144 Gallons	

APPENDIX C

Aircraft Operating Expenses

The Civil Aeronautics Board (Ref. 1) published the operating costs of aircraft operated by the U.S. certified air carriers for twelve month periods. The operating costs are tabulated by block hours and are divided into the categories of flying operations, maintenance, and depreciation/rentals. Only the first two categories have potential as cost saving due to the implementation of FAD procedures.

The dominant costs of flight operations are crew labor and fuel. In 1974 crew and fuel costs accounted for more than 98 percent of total flight operational costs. A trade publication (Ref. 3) indicates that by 1975 this figure had increased to 99 percent.

Discussions with the Air Transportation Association (Ref. 4) and several airlines (Refs. 5,6) indicated that there is a reduction in crew costs for the time prior to engine-on time at the gate. A representative of the Airline Pilots Association (Ref. 7) stated that there are as many contracts as there are airlines, but a general rule is that the crew are paid on the basis of scheduled or actual time, whatever is greater. The general consensus was that the crew costs should be considered the same whether the aircraft is holding in the air or at the originating airport. For cases where the aircraft would have to be taxied away from the gate before absorbed the ground delay, the crew would be paid at the full rate for all imposed ground time. Consequently, for this study it was decided that no differentiation was to be made between crew costs while holding in the air or on the ground.

Fuel costs are the major costs differences between holding in the air or on the ground. Delta Airlines (Ref. 8) provided holding fuel consumption rates for their aircraft mix at an altitude of 15,000 feet for aircraft with "clean" configuration and with flaps extended. Delta stated that 15,000 feet was their typical holding altitude at Chicago.

A review of aircraft manufacturer's data (Ref. 10 through 14) indicated that the fuel consumption rates obtained from Delta generally were at the aircrafts' gross weight midpoint. Data was also obtained from American Airlines (Ref. 9) for typical fuel consumption rates while holding at terminal areas for their fleet mix. Their stated fuel consumption rates were at a slightly higher rate than Delta Airlines.

For consistency in this study all fuel consumption rates were extracted from the manufacturer's data at a holding altitude of 15,000 feet and at the midpoint gross weight of their performance curves or charts. To be conservative the minimum holding fuel consumption rates were used. The selection of the midpoint gross weight appears to be the logical choice for the following reasons:

(1) It agrees with the data obtained from the airlines.

(2) The stage lengths of the flights will be of various lengths resulting in various aircraft gross weights in the terminal area.

(3) The aircraft loads (passenger and cargo) will vary resulting in different gross weights.

(4) The aircraft gross weights will vary dependent on whether a scheduled refueling is to be made at the terminal airport.

For the purpose of this study it was assumed that the taxi/idle ground fuel consumptions were equivalent whether the aircraft had an imposed FADP ground delay, or take-off occurred at the original schedule time. This assumes that the taxiway queue times at the end of the FADP ground delay and the originally scheduled time frames were the same. Therefore, the decreased airborne holding time results in the FADP fuel saving benefits when multiplied by the holding fuel consumption rates.

Fuel saving benefits were computed for eight categories of aircraft. The categories and the fuel consumption rates were calculated from manufacturers' data (Refs. 10-13, 17-19) and are listed below:

Category	Gallons Per Minute
4 Engine Wide Body Jet	50.3
3 EngineeWide Body Jet	29.0
4 Engine Regular Body-Stretch Jet	25.3
4 Engine Regular Body Jet	22.8
3 Engine Regular Body Jet	16.8
2 Engine Reular Body Jet	11.0
Turboprop	3.7
All Others (piston engine aircraft)	1.0

Cost savings for the first seven categories were based on a fuel cost of $0.31 per gallon. The "All Other" category fuel savings was based on a fuel cost of $0.70 per gallon.

When data in the above listing was used in AIRS, one fuel consumption rate was used for the majority of the general aviation aircraft. This number has not been verified but the total savings for this category contribute on the order of 0.1 percent of the total fuel savings so it has little significance.

In addition, the fuel consumption rate for the turboprop category was based on the two engine CV-580. (The fuel consumption rate for the FH-227B is approximately the same). In all the runs checked this category contributed less than 5 percent of the fuel savings.

An effort was also made to determine if a difference could be determined between maintenance costs corresponding to airborne holding vs. holding on the ground. Several airlines were contacted but only one indicated they used a differential between airborne and ground maintenance costs.

A Pratt and Whitney respresentative (Ref. 15) stated that the major maintenance costs associated with engines are in the takeoff, climb, and cruise portion of a flight with the first two phases predominant with respect to engine life. They estimated that the descent and holding phases contribute less than 1 percent of engine maintenance costs, while idling on the ground would be less than 0.5 percent. In addition, engines are no longer cycled for maintenance on the basis of airborne hours (Ref. 2). A variety of engine parameters are constantly monitored and these parameters determine when an engine should have major maintenance. Therefore, it was their recommendation that no engine maintenance cost differential be used in this study.

APPENDIX D

SENSITIVITY OF RESULTS

SENSITIVITY TO GROSS WEIGHT ASSUMPTION

The sensitivity of FADP were examined as indicated below.

The fuel consumption savings were calculated on the basis that the airborne delays would occur at average holding altitude of 15,000 feet and at the midpoint gross weight as shown on the manufacturers' holding curves and charts. There are an unlimited number of combinations of altitudes and aircraft gross weights. Due to limitations in available data and for brevity it was decided that fuel consumption sensitivity would be calculated as follows:

- o Holding altitude fuel consumption rates at 5000 feet and 25,000 feet were compared to the 15,000 feet holding fuel consumption rates with the midpoint gross weights used in all calculations.

- o The minimum and maximum holding gross weight fuel consumption rates were compared to the midpoint gross weights with a 15,000 feet holding altitude used in all calculations.

The results of these calculations are shown in Table D-1.

Table D-1

FUEL CONSUMPTION RATES AS A FUNCTION OF HOLDING ALTITUDE AND AIRCRAFT GROSS WEIGHT

(Nominal Values: 15,000 feet holding altitude, midpoint gross weight)

Aircraft type	Percent Difference from Nominal Values			
	Holding Altitude		Gross Weight	
	5000 ft.	25,000 ft.	Minimum	Maximum
4 engine wide body	+5.8	-2.9	-24.9	+27.8
3 engine wide body	+5.1	-1.7	-23.1	+34.2
4 engine reg. body	+4.8	-3.9	-35.9	+30.1
4 engine reg. body	+3.9	-6.0	-23.6	+22.8
3 engine reg. body	+6.9	-4.0	-19.7	+12.8
2 engine reg. body	+8.5	-5.4	-13.4	+15.8

The above data was then applied to the simulation run for Chicago of 2-5-75, which was the run of maximum impact. The nominal values resulted in a fuel savings of 1,264,632 gallons. The above six categories accounted for 1,206,793 gallons (95.4%) of the fuel savings.

Table D-2 delineates the difference in fuel savings for these six categories as functions of holding altitude and aircraft gross weight.

Table D-2

COMPARISON OF FAD PROCEDURES FUEL SAVINGS AS FUNCTIONS OF HOLDING ALTITUDE AND AIRCRAFT GROSS WEIGHT (CHICAGO 2-5-75)

CONDITION	FUEL CONSUMPTION - GALLONS	PERCENT DIFFERENCES FROM NOMINAL
15,000', mid gross weight	1,208,793	0
5,000', mid gross weight	1,284,813	+6.5
25,000', mid gross weight	1,155,774	-4.2
15,000', max gross weight	1,429,768	+18.5
15,000', min gross weight	964,298	-20.1

Table D-2 indicates that the selection of 15,000 feet as a nominal holding altitude had a relatively minimum effort on the FADP simulation results. The table indicates that the minimum and maximum aircraft gross weights have considerably more effect on the results. However, as previously discussed, the midpoint gross weight seems to be the most reasonable figure to use in the simulation. Also there apppears to be a slight probability that many aircraft would be holding at the minimum or maximum holding gross weights delineated by the manufacturers. Therefore, the practical effects of aircraft gross weights would be considerably less than shown in Table D-2.

SENSITIVITY OF THE BENEFITS TO REDISTRIBUTION OF TRAFFIC LOADS

In modeling a given problem day for an airport, two sets of data must be prepared, the hourly arrival traffic loads and the hourly landing capacities. The preparation of traffic loads start with a given (exact) traffic load condition experienced during the airport's 1975 actual problem situation to be extrapolated into the future. A given percentage traffic increase (from 3rd generation FAA system study) is applied to these hourly traffic loads. To approximate a rescheduling of this traffic if greatly over the normal given capacity, a spread algorithm was employed. The algorithm is given an allowable percentage over normal landing capacity and if the increase load exceeds this allowable schedule, it spreads the excess traffic into the nearest hours where no excess exists. The spread is divided uniformly, half being spread into earlier hours and half spread into later hours. Obviously, this traffic spread is controlled such that it does not overload any other hour.

The hourly landing capacity is also obtained from the actual problem day in 1975 and the hours for which no data was recorded are given the normal IFR capacity value.

The FADP benefits were calculated using FAA yearly demand predictions for the FY 1980, 1985, and 1990, assuming the baseline UG3RD was operational during this period, and using the same fleet mix as in the baseline assessment. The 1975 hourly demands for the four airports were increased proportionally to match the FAA yearly expansions. Four cost benefit assessments were then made as a function of hourly demand distribution. These were:

1. Hourly demand allowed to exceed capacity.

2. Hourly demand redistributed to other hours when demand exceeded capacity by 20%.

3. Hourly demand redistributed to other hours when demand exceeded capacity by 10%.

4. Hourly demand redistributed to other hours when demand exceeded capacity.

Table D-3 presents the computed benefits for these cases.

Using the no redistribution case as the base, the following restates the results of Table D-3 as a percentage:

Year	48 Minute FADP			30 Minute FADP		
	20%	10%	0%	20%	10%	0%
1980	.3%	.3%	10%	.3%	.8%	9%
1985	.3%	1.8%	10.5%	.3%	1.1%	9.6%
1990	.3%	1.9%	12%	.3%	1.2%	11.2%

TABLE D-3

FADP FUEL SAVINGS RESULTS

FADP CRITERION	DEMAND DISTRIBUTION	FUEL SAVINGS IN GALLONS (1000)/DOLLARS (1000) 1980	1985	1990
48 minutes	1. No Redistribution	13581/ 4209	16879/ 5232	19190/ 5920
	2. > 20% Redistribution	13535/ 4195	16828/ 5217	19146/ 5907
	3. >10% Redistribution	13364/ 4142	16571/ 5136	18819/ 5806
	4. > 0% Redistribution	12218/ 3787	15098/ 4680	16888/ 5207
30 minutes	1. No Redistribution	17462/ 5414	21038/ 6521	23478/ 7278
	2. > 20% Redistribution	17419/ 5400	20988/ 6506	23477/ 7266
	3. > 10% Redistribution	17310/ 5367	20798/ 6447	23184/ 7188
	4. > 0% Redistribution	15876/ 4922	19004/ 5890	20848/ 6463

These results indicate that the cases where projected demand exceeds the normal airport capacity by more than 10% for any given hour have an insignificant effect on the overall benefit results. Further, even if the demand were spread throughout the day such that the hourly scheduled demand never exceeded the normal hourly capacity of an airport, the impact on the overall benefits would be approximately 10%.

APPENDIX E

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22. A Proposed Concept for Flow Control Automation, Report No. MTR-6589, The Mitre Corporation, April 10, 1974

APPENDIX F

ANNUAL DEMAND/CAPACITY IMBALANCE

TABLE F-1

1975 SIMULATED FADP RUNS WITH CAUSES OF CAPACITY REDUCTION

(January thru November)

AIRPORT	DATE	CAUSES OF CAPACITY REDUCTION
ORD	1-8	Low Ceiling and Visibility
ORD	1-9	Volume, Heavy Jet Mix
ORD	1-10	Thunderstorms, High Shifting Winds
ORD	1-29	Winds
ORD	2-5	Snow
ORD	2-15	Snow, Below Minimums
ORD	2-23*	Localizer Failure
ORD	2-25	Winds, Low Ceiling, Snow
ORD	3-24	Decreased Visibility, Snow
ORD	3-27*	Winds, Icing, Demand, ILS Loss
ORD	4-2	Snow, Visibilities, Two ILS Failures
ORD	4-3	Snow
ORD	4-18	Thunderstorms, Demand
ORD	4-19	Winds, Runway Closure for "Soil Evaluation"
ORD	5-30	Thunderstorms
ORD	6-12	Winds, Reduced Visibility
ORD	6-17	Thunderstorms
ORD	8-20*	Thunderstorms
ORD	8-22*	Thunderstorms
ORD	9-11	Winds, Aircraft Emergency
ORD	10-17	Winds
ORD	10-22*	Winds, Demand
ORD	10-23*	Runway Closed, Winds, Computer Outage
ORD	10-24	Weather
ORD	10-31	Winds
ORD	11-2 *	Demand
ORD	11-9	Demand
ORD	11-13	Winds
ORD	11-26	Snow, Low Ceiling and Visibility

AIRPORT	DATE	CAUSES OF CAPACITY REDUCTIONS
JFK	1-11	Below Minimums
JFK	1-18	Winds
JFK	2-5	Winds, Snow Removal
JFK	3-19	Weather, Departures, Volume, Runway Configuration
JFK	4-24	IFR Weather, "Scan" Failure, Weather Below Minimums
JFK	6-12	One Runway for Arrivals Combined with Low Ceiling, Low Visibility and Traffic Volume
JFK	6-15	Low Ceiling, No Visual Approaches
JFK	6-16	Demand Exceeded Capacity for One Landing Runway with IFR Weather
JFK	6-24	Airport Accident
JFK	6-28	Demand, Weather
JFK	7-13	Thunderstorms, Runway Closed for Inspection
JFK	8-4	Weather
JFK	8-24	Thunderstorms, Runway Configuration, Demand
JFK	8-25	Below Minimums
JFK	8-26	Low Ceiling, Low Visibility
JFK	10-25	Alternating Approaches with LGA, Runway Change, Weather
JFK	11-12	Crash, Weather, ILS Failure
JFK	11-13	Winds
JFK	11-14	Disabled Aircrafts Caused Single Runway Operation
JFK	11-21	Thunderstorms, High Winds
JFK	11-30	Strong Winds, Low Visibility
LGA	1-13	Weather, Sanding of Runway
LGA	1-20	IFR Weather, Icy Runway Caused Poor Breaking Action
LGA	1-25	Weather Below Minimum, Glide Slope Out of Service
LGA	3-12	Strong Gusty Winds
LGA	3-14	Weather Below Minimums, Runway Closed for Sanding
LGA	3-19	Weather, Sanding of Runway
LGA	5-4*	Weather, One Runway Operation Due to JFK ILS Approaches, Conflicting Flow Between LGA and TEB

AIRPORT	DATE	CAUSES OF REDUCED CAPACITY
LGA	8-4	Weather
LGA	9-26	Winds, ILS Failure
LGA	11-21	Winds, Wet Runways
LGA	11-24 *	Winds
LGA	11-30	Winds, Visibility
ATL	2-1	Weather Below Minimum
ATL	2-19 *	Low Ceiling, Runway Localizer Inoperative
ATL	2-23	Weather Below Minimum
ATL	3-12	Low Ceiling, Low Visibility, and RVR
ATL	9-7	Low Ceiling, Low Visibility, Airport Below User Minimums
ATL	11-24	Below Minimums, Runway Repairs, Winds

* Applies only to advanced system 30-minute threshold capability.

APPENDIX G

SENSITIVITY OF BENEFIT-TO-COST RATIO TO COST ESCALATION AND IMPLEMENTATION DELAY

INTRODUCTION

This study was undertaken to determine the sensitivity of the calculated Central Flow Control Automation Program (CFC) Benefit-to-Cost Ratio (BCR) to major program uncertainty. Analysis indicated that major program uncertainty existed only in the area of software development estimates. Two aspects of software development estimation uncertainty were identified and explored; escalation of software development costs, and implementation delay due to software development. These aspects were examined both singly and in conjunction.

Cost Escalation. To isolate the effects of software development cost escalation, the estimated software development costs were separated from total costs and discounted at a 10% rate to be consistent with the Cost Benefit Study. Escalation factors of 200%, 250%, 400%, and 500% were applied with the expenditure period held constant.

The incremental discounted costs associated with each escalation factor were then applied to the total discounted differential costs (Table 7), and adjusted BCR's based on the total discounted differential benefits (Table 7) were computed.

The following shows the discounted software development cost estimates: (all figures $ X 1000)

	100%		200%		250%		400%		500%	
FY	EST.	P.V.	EST.	P.V.	EST.	P.V.	EST	P.V.	EST.	P.V.
1977	1000	1000	2000	2000	2500	2500	4000	4000	5000	5000
1978	2000	1818	4000	3636	5000	4545	8000	7272	10000	9090
1979	2000	1652	4000	3304	5000	4130	8000	6608	10000	8260
TOT.	5000	4470	10000	8940	12500	11175	20000	17880	25000	22350
DEV.		0		4470		6705		13410		17880

BCR's based on escalated cost figures are as follows:

2

ESCALATION FACTOR	BENEFIT ($ X 1000) /	COST ($ X 1000)	BCR
200%	21792	(8457 + 4470)	1.68
250%	21792	(8457 + 6705)	1.43
400%	21792	(8457 + 13410)	0.99
500%	21792	(8457 + 17880)	0.82

Implementation Delay. To isolate the effects of implementation delay due to software development, three program aspects were examined; the discounted cost variance resulting from "spreading" the expenditure period with the expenditure amount held constant, the discounted cost variance associated with unanticipated retention of present system costs, and the discounted benefit variance attributable to the lowered benefit potential resulting from unanticipated retention of the present system.

The estimated software development costs were separated from total costs and discounted at a 10% rate to be consistent with the Cost Benefit Study. As the estimated expenditures are uniformly applied over the estimated implementation period, uniform expenditures over implementation periods escalated by factors of 200%, 250%, 400%, and 500% were calculated with the expenditure amount held constant. The incremental discounted costs associated with each escalation factor were then calculated.
Table G-1 shows the "spread" discounted costs. (all figures $ X 1000)

The costs of present system retention (computer leasing; c.f. Table 3) were separated from total costs and discounted at a 10% rate. Retention costs were applied to implementation periods escalated by factors of 200%, 250%, 400%, and 500%, as above, and the incremental discounted costs associated with retention were calculated. Table G-2 shows the discounted retention costs. (all figures $ X 1000)

	100%		200%		250%		400%		500%	
FY	EST.	P.V.	EST.	P.V.	EST.	P.V.	EST.	P.V.	EST.	P.V.
1977	1000	1000	500	500	400	400	250	250	200	200
1978	2000	1818	1000	909	800	727	500	454	400	364
1979	2000	1652	1000	826	800	661	500	413	400	330
1980			1000	751	800	601	500	376	400	300
1981			1000	683	800	546	500	342	400	273
1982			500	310	800	497	500	310	400	248
1983					600	338	500	282	400	226
1984							500	256	400	205
1985							500	234	400	187
1986							500	212	400	170
1987							250	96	400	154
1988									400	140
1989									400	128
1990										
TOT.	5000	4470	5000	3979	5000	3770	5000	3225	5000	2925
DEV.		0		(491)		(700)		(1245)		(1545)

TABLE G-1
"SPREAD" DISCOUNTED SOFTWARE
DEVELOPMENT COSTS

	100%		200%		250%		400%		500%	
FY	EST.	P.V.	EST.	P.V.	EST.	P.V.	EST.	P.V.	EST.	P.V.
1977	560	560	560	560	560	560	560	560	560	560
1978	560	509	560	509	560	509	560	509	560	509
1979			560	463	560	463	560	463	560	463
1980			280	210	560	421	560	421	560	421
1981					140	96	560	382	560	382
1982							560	348	560	348
1983							280	158	560	316
1984									560	287
1985										
1986										
1987										
1988										
1989										
1990										
TOT.	1120	1069	1960	1742	2380	2049	3640	2841	4480	3286
DEV.		0		673		980		1772		2217

TABLE G-2
DISCOUNTED RETENTION COSTS

Benefits over the expected system life were recalculated for implementations with implementation periods escalated by factors of 200%, 250%, 400%, and 500%, and incremental discounted benefit variances associated with each escalation factor were computed. Table G-3 shows the discounted benefits associated with present system retention. (all figures $ X 1000)

For each implementation period escalation factor, the incremental discounted costs associated with expenditure "spreading" and present system retention were applied to the total discounted differential costs (Table 7). The incremental discounted benefits associated with present system retention were applied to the total discounted differential benefits (Table 7), and adjusted BCR's were computed. BCR's based on escalated implementation period figures are as follows:

ESCALATION FACTORS	BENEFIT / COST ($ X 1000) ($ X 1000)	BCR
200%	(21792-3440)/(8457-491 + 673)	2.12
250%	(21792-5139)/(8457-700 + 980)	1.91
400%	(21792-9865)/(8457-1245 + 1772)	1.38
500%	(21792-12741)/(8457-1545 + 2217)	0.99

Cost Escalation and Implementation Delay. To examine the combined effects of cost escalation and implementation delay, the calculations used in computing the effects of implementation delay were used as a base.

The incremental software development discounted costs associated with each implementation period escalation factor were escalated by expenditure factors of 200%, 250%, 400%, and 500%, as was done with original estimate under Cost Escalation, above. The present system retention incremental discounted costs and the related incremental discounted benefit variances associated with each implementation period escalation factor remained constant, as neither is affected by software development cost escalation.

FY	100% EST.	100% P.V.	200% EST.	200% P.V.	250% EST.	250% P.V.	400% EST.	400% P.V.	500% EST.	500% P.V.
1977	3884	3884	3884	3884	3884	3884	3884	3884	3884	3884
1978	4500	4090	4500	4090	4500	4090	4500	4090	4500	4090
1979	7897	6523	5117	4227	5117	4227	5117	4227	5117	4227
1980	8788	6600	7260	5452	5733	4305	5733	4305	5733	4305
1981	9361	6394	9361	6394	8559	5846	6151	4201	6151	4201
1982	9933	6168	9933	6168	9933	6168	6569	4079	6569	4079
1983	10506	5925	10506	5925	10506	5925	8746	4933	6987	3941
1984	11078	5683	11078	5683	11078	5683	11078	5683	7405	3799
1985	11651	5441	11651	5441	11651	5441	11651	5441	11651	5411
1986	12042	5106	12042	5106	12042	5106	12042	5106	12042	5106
1987	12433	4799	12433	4799	12433	4799	12433	4799	12433	4799
1988	12825	4489	12825	4489	12825	4489	12825	4489	12825	4489
1989	13216	4216	13216	4216	13216	4216	13216	4216	13216	4216
1990	13607	3946	13607	3946	13607	3946	13607	3946	13607	3946
TOT.	141721	73264	137413	69820	135084	68125	127552	63399	122120	60523
DEV.		0		(3440)		(5139)		(9865)		(12741)

TABLE G-3

DISCOUNTED BENEFITS ASSOCIATED WITH RETENTION

For each cost escalation factor for an implementation period escalation factor, the incremental discounted costs associated with the cost factor and the incremental discounted costs associated with the delay factor were applied to the total discounted differential costs (Table 7), the incremental discounted benefit variance associated with the delay factor was applied to the total discounted differential benefits cost factor for each delay factor. The following shows "spread" costs (Table G-1) adjusted for cost escalation: (all figures $ X 1000)

COST FACTOR	DELAY FACTOR 200%	250%	400%	500%
200%	7958	7540	6450	5850
250%	9948	9425	8062	7312
400%	15916	15080	12900	11700
500%	19895	18850	16125	14625

Expressing these as a deviation from the expected discounted software development costs (Table G-1): (all figures $ X 1000)

COST FACTOR	DELAY FACTOR 200%	250%	400%	500%
200%	3488	3070	1980	1380
250%	5478	4955	3592	2842
400%	11446	10610	8430	7230
500%	15425	14380	11655	10155

These cost figures, adjusted for retention costs (Table G-2) are as follows: (all figures $ X 1000)

COST FACTOR	DELAY FACTOR 200%	250%	400%	500%
200%	4161	4050	3752	3597
250%	6151	5935	5364	5059
400%	12119	11590	10202	9447
500%	16098	15360	13427	12372

Using benefit figures adjusted to reflect present system retention as in implementation delay BCR calculation above, and the above cost figures with the basic system cost (Table 7) added, BCR's based on both escalated cost and escalated implementation period combined are calculated as follows: (all figures $ X 1000)

COST FACTOR	DELAY FACTOR 200%	250%	400%	500%
200%	18352/12618	16653/12507	11927/12209	9051/12054
250%	18352/14608	16653/14392	11927/13821	9051/13516
400%	18352/20576	16653/20047	11927/18659	9051/17904
500%	18352/24555	16653/23817	11927/21884	9051/20829

The following adjusted BCR's fesult:

COST FACTOR	DELAY FACTOR 200%	250%	400%	500%
200%	1.45	1.33	0.98	0.75
250%	1.26	1.16	0.86	0.67
400%	0.89	0.83	0.64	0.50
500%	0.75	0.70	0.54	0.43

CONCLUSIONS

The adjusted BCR's for the three cases, cost escalation alone, implementation delay alone, and combined cost escalation and implementation delay, are summarized as follows:

PERCENT BASE COST ESTIMATE	PERCENT BASE IMPLEMENTATION PERIOD ESTIMATE				
	100%	200%	250%	400%	500%
100%	2.58	2.12	1.91	1.38	0.99
200%	1.68	1.45	1.33	0.98	0.75
250%	1.43	1.26	1.16	0.86	0.67
400%	0.99	0.89	0.83	0.64	0.50
500%	0.82	0.75	0.70	0.54	0.43

With the implementation period held constant as estimated, a doubling of the software cost reduces the BCR by 35% from 2.58 to 1.68; a quadrupling of the software cost reduces the BCR by 62% from 2.58 to 0.99.

With the cost held constant as estimated, a doubling of the length of the implementation period reduces the BCR by 18% from 2.58 to 2.12; a quadrupling of the length of the implementation period reduces the BCR by 46% from 2.58 to 1.38.

The BCR is more sensitive to cost escalation within implementation period than to implementation delay within cost estimate, but neither problem taken singly can be seen to have significant effects even at levels of gross estimate deviation.

In combination, a doubling of both software cost and length of implementation period reduces the BCR by 44% from 2.58 to 1.45; increasing both by a factor of 2½ times current estimates reduces the BCR by 55% from 2.58 to 1.16. The combined effects of both problems are more significant than either problem taken singly at the same level of estimate deviation, but less significant than the sum of the effects of the two problems at the same level. The effects of combined estimation errors are not seen as significant except at levels of gross estimate deviation in both areas.